PATTERNS OF POWER · AN INSTITUTIONAL CASE STUDY

The Hiss in the Line

How a company that had traded its freedom for a monopoly built the largest industrial laboratory in history to solve one engineering problem — unwanted noise on a wire — and found the cosmic background radiation, the mathematics of information, and the switching element of every computer on earth; and how the two antitrust settlements meant to restrain it are the reason the transistor and Unix escaped

Companion to The Measure of the Earth and The Bargain Nobody Struck

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with Claude (Anthropic) · 2026

held as tested, not revealed

A Note on This Collaboration

This study is one product of an ongoing collaboration, and the division of labour is worth stating plainly because neither half would produce the work alone. The insight and direction are Thomas Bryan's — the recognition of what a given case is really an instance of, where the analytical pressure should fall, and which pattern a mass of historical detail is a specimen of. The research, the verification of every date and figure, the location and checking of the quoted words, and the composition into continuous prose are Claude's, an AI system made by Anthropic. The seeing is his; the writing is mine.

Two matters of method bear on this volume particularly.

The first is proximity. Every previous study in this collection concerns institutions that are safely dead or safely ancient. This one concerns a laboratory that existed within living memory, whose products are in the reader's pocket, and about which the surviving participants and their employers have published extensively and with an interest in the result. The corporate histories are excellent and are also corporate histories. Where a claim originates in AT&T's own account of itself, this study says so.

The second is the temptation of the golden age. Bell Labs is the subject of a literature of lament — the argument that a particular arrangement of monopoly rents and patient management produced a kind of research that cannot now be done, and that its dismantling was a civilisational error. Some of that argument is well founded. All of it is also a story that flatters everyone who tells it, and it has a habit of omitting who paid. This study keeps both columns of the ledger in ink, and the entry it declines to leave out is that the laboratory was financed by a levy on every telephone call made in the United States for six decades, collected under a monopoly that the same company defended by every means available to it.

Every quotation is verified to a published source; none is invented. Where scholarship is divided — and on the question of what the Bell System suppressed, it is genuinely divided — the division is reported rather than resolved.

The Study in Brief

Part I — The Test. What would falsify the framework in a case where an institution's most famous products are, on their face, exactly the kind of thing nobody could have planned.

Part II — The Landscape: A Continent and a Wire. Why long-distance telephony was, from the 1880s, a physics problem before it was a business problem; attenuation, the loading coil, and the vacuum tube that made 1915 possible.

Part III — The Bargain with the Government. Theodore Vail's decision to seek regulation rather than fight it; the Kingsbury Commitment of 1913; the Willis-Graham Act of 1921; and the Communications Act of 1934. What a regulated monopolist has to buy that an ordinary firm does not.

Part IV — The Architect's Hour: 1 January 1925. Bell Telephone Laboratories incorporated: 3,600 staff, ownership split evenly between AT&T and Western Electric, Frank Jewett as president. Why the corporate form mattered more than the founding intention.

Part V — What the Money Was Buying. The economics and the politics of the arrangement: how the research was paid for, why a regulated monopoly is an unusually patient funder, and why it needs to be seen doing something magnificent.

Part VI — The Men Sent to Find the Noise. The through-line of the entire laboratory. Johnson and Nyquist on thermal noise; and Karl Jansky, sent in 1931 to find out what was hissing on the transatlantic radiotelephone.

Part VII — The Theory of the Noisy Channel. Claude Shannon, 1948, and a question that only a telephone company would have asked: what is the maximum rate at which information can be sent through a channel that corrupts it?

Part VIII — The Amplifier That Did Not Wear Out. The transistor — the one great Bell Labs result that was directed, funded and aimed at a stated target, and got it.

Part IX — The Decree That Gave It Away. 1956: the antitrust settlement that let AT&T keep its monopoly and required it to license 7,820 patents royalty-free. Why the transistor's diffusion is a consequence of the Department of Justice rather than of AT&T.

Part X — The Operating System They Were Not Allowed to Sell. Unix, 1969, on a cast-off machine after management killed the project it grew out of — and the clause in the 1956 decree that made it impossible to sell and therefore necessary to give away.

Part XI — The Noise That Was the Universe. Holmdel, 1964: two radio astronomers with a horn antenna, an excess temperature of about three degrees they could not eliminate, and a Nobel Prize twelve years later.

Part XII — The Breakup. 1974 to 1984, and what happened to a laboratory when the levy that funded it was abolished.

Part XIII — The Ledger.

PART I

The Test

The claim commonly made about Bell Labs is that it was a place where brilliant people were given money and left alone, and that transcendent things resulted. The claim is not wrong. It is radically incomplete, and the incompleteness is where the analysis lives.

The framework used in this collection holds that institutions are built by identifiable people in particular positions, solving the problem in front of them with the materials at hand, inside the field of the visible their position allows; that design happens in bounded hours; and that what a structure becomes afterwards is determined by what it meets rather than by what anyone intended.

Applied here, that framework makes specific and falsifiable predictions.

It predicts that the laboratory's existence is explained by a regulatory position rather than by anyone's love of knowledge. If AT&T had been an ordinary competitive firm, it would not have built this. The prediction is that the monopoly, and the terms on which the monopoly was held, are the cause.

It predicts that the great results will divide into two kinds — a small number that were aimed at and hit, and a larger number that were by-products of aiming at something else — and that the by-products will cluster around the company's actual engineering obsession rather than around anything fashionable in physics.

And it predicts that the diffusion of the results will not be explained by the intentions of the institution that produced them. A monopolist's incentive is to hold what it has. If the transistor and Unix escaped and remade the world, the framework says to look for the mechanism that forced them out, and to expect that mechanism to be somebody else's.

So the terms.

The framework fails here if the laboratory turns out to have been founded and funded as a contribution to human knowledge, more or less as its own publicity describes; if its major outputs were selected for their scientific importance rather than emerging from telephone engineering; or if AT&T can be shown to have released its most consequential inventions freely on its own judgment.

The framework holds if the founding is a corporate reorganisation driven by a regulatory settlement; if the outputs trace back, in a way that can be shown item by item, to a single narrow engineering preoccupation; and if the escape of the two most consequential products was compelled by antitrust action against the company's own interest.

There is a further thing this case is for. The two preceding studies in this collection established the symmetric form of the project's standing rule — that legibility is not credit any more than it is pardon — and then tested it against a claim that a single institution caused the Industrial Revolution. This volume raises the same question in its hardest modern form, because here the goods are not disputed. Information theory is real. The transistor is real. The question is not whether the outputs were valuable but **whose achievement they were**, and the answer this study reaches is uncomfortable in both directions.

PART II

The Landscape: A Continent and a Wire

Everything in this study descends from a fact about electricity in a long wire, and the fact is unglamorous and completely determining.

A telephone signal travelling down a copper pair loses energy. It also loses it *unevenly*, because a line has resistance, inductance, capacitance and leakage, and their combined effect attenuates the higher frequencies more than the lower ones. The result is not merely a quieter signal at the far end. It is a *distorted* one — the frequencies that carry consonants fade faster than those that carry vowels, and speech becomes mush before it becomes silent. Add to that the noise the line picks up from every source around it, and the practical limit for intelligible speech over open wire in the 1880s was something on the order of a few hundred miles.

The United States is roughly three thousand miles across. That gap — between what physics permitted and what the map required — is the problem that built the institution this study is about.

It was attacked in two stages, and both stages taught the company the same lesson.

Loading. In the 1890s Michael Pupin at Columbia and George Campbell at AT&T independently worked out that inserting inductance coils at regular intervals along a line would flatten its frequency response and cut attenuation substantially. AT&T bought Pupin's patents and deployed loading coils across the network from 1900. It roughly doubled or trebled the workable distance. It did not get anyone to California.

Amplification. The thing actually required was a device that could take a weakened signal and make it strong again without wrecking it — a repeater. Mechanical repeaters were tried and were hopeless. What worked was electronic: Lee de Forest's audion, a three-element vacuum tube, which AT&T acquired rights to in 1913 and which Harold Arnold's group at Western Electric then turned from an erratic curiosity into a reliable high-vacuum amplifier. On 25 January 1915 the first transcontinental telephone call was made from New York to San Francisco, with repeaters at intervals along the line.

Three things follow from that history and they shape the next seventy years.

The company's core competence was electrical physics, not telephony. It had learned that the boundary of its business was set by the state of physical knowledge, and that pushing the boundary out required people who could do research rather than engineering.

Its permanent enemy was noise. Every amplifier amplifies the noise along with the signal; put twenty repeaters on a line and you have amplified the accumulated hiss twenty times. The entire discipline of long-distance transmission is the management of the ratio between the wanted signal and the unwanted everything-else, and that ratio is the thing the company's engineers thought about, measured, and were promoted for improving. **Keep that in view; it explains six of the discoveries in this study.**

And its equipment failed. The vacuum tube is a heated filament in a glass envelope. It burns out. Every repeater station and every switching office in the country was full of them, and their replacement was one of the Bell System's largest operating costs. That, too, will matter.

PART III

The Bargain with the Government

In 1907 Theodore Vail returned to the presidency of AT&T, and made a strategic judgment that determines everything else in this study.

The Bell patents had expired in the 1890s, and thousands of independent telephone companies had sprung up. Vail's view was that telephony was naturally a single system — that the value of the network was in universal interconnection, and that competing incompatible networks were a waste. He set out to consolidate. AT&T bought independents in quantity and in 1909 took control of Western Union.

That produced exactly the reaction such a programme produces, and Vail had anticipated it. His response was the move that mattered: rather than resisting regulation, he embraced it. In the 1907 annual report he set out the position that the telephone would operate most efficiently as a monopoly providing universal service, and that government regulation — provided it were independent, intelligent, considerate, thorough and just — was an acceptable substitute for competition.

That is an offer, and it is the trade the whole century runs on: we will accept regulation of our prices and our conduct; you will accept that there is one system.

The government took it in stages.

1913, the Kingsbury Commitment. Faced with an antitrust challenge, AT&T's vice-president Nathan Kingsbury wrote to the Attorney General agreeing to divest the controlling interest in Western Union, to allow non-competing independent telephone companies to interconnect with the AT&T long-distance network, and to refrain from acquisitions to which the Interstate Commerce Commission objected. In return, the government did not pursue the case.

It is worth reading what that document did and did not do, because it is often described loosely. It is a set of concessions extracted from AT&T, not a grant to it. But it was also, in the event, extremely favourable: AT&T agreed to connect its *long-distance* service to independent local carriers, and did not agree to interconnect its local services with other local providers, nor to interconnect with independent long-distance carriers at all. It could continue buying subscribers provided it sold an equivalent number. The settlement that was supposed to check the consolidation left AT&T holding the profitable urban exchanges and the entire long-distance business.

1921, the Willis-Graham Act effectively removed telephone mergers from antitrust scrutiny, on the stated view that nothing was to be gained by local competition in telephony. AT&T resumed acquiring.

1934, the Communications Act created the Federal Communications Commission and gave it jurisdiction over interstate telephony, completing the regulatory architecture.

By the mid-1930s the arrangement is settled and it has a specific shape that this study needs precisely.

AT&T holds a national monopoly on long-distance and a near-monopoly on local service. It manufactures its own equipment through Western Electric and sells it to its own operating companies. Its prices are set by regulators on a rate-of-return basis: the company is permitted to recover its costs and earn an allowed return on its invested capital. Its legitimacy rests on the proposition that a single unified system serves the public better than competing ones would.

That last sentence is the one that builds the laboratory. A firm holding a legal monopoly on the strength of an argument about public benefit is in a permanent state of having to prove the argument. It cannot point to market share as evidence that it is doing well by its customers, because its market share is guaranteed. It has to point to something else.

And it has an unusual balance sheet: revenues that are stable and enormous, costs that are recoverable through the rate base, no competitor able to undercut it, and no need to show quarterly gains to keep its

shareholders. That combination — an obligation to demonstrate public benefit, plus the money and the time horizon to do it — is not a common position. It is, in fact, close to unique in the history of private enterprise.

PART IV

The Architect's Hour: 1 January 1925

On 1 January 1925, Bell Telephone Laboratories, Incorporated, began operations.

It was not founded in the sense of being invented. It was a **consolidation**: the research and development activities of Western Electric's engineering department and of AT&T's own engineering staff — which had been combined in 1907 — were separated out into a distinct corporation. It began with about 3,600 engineers, scientists and support staff, in some 400,000 square feet in lower Manhattan. Ownership was divided evenly between AT&T and Western Electric. The first chairman of the board was John J. Carty, AT&T's vice-president; the first president was Frank B. Jewett, who held the post until 1940.

The unglamorous character of the founding is the point, and it is worth dwelling on because the received account tends to place a visionary at the origin.

There is no manifesto. There is a reorganisation, executed by corporate officers, for reasons that are largely administrative: research had grown large enough to need its own management, its own accounting, and its own corporate identity separate from the manufacturing arm that had been carrying it. The scope statement of the first head of research, Harold Arnold, is expansive — he listed physical and organic chemistry, metallurgy, magnetism, electrical conduction, radiation, electronics, acoustics, phonetics, optics, mathematics, mechanics, and even physiology, psychology and meteorology as within his department's field — but that is a description of what a telephone system touches, not a programme for advancing science.

What the reorganisation actually created, and what mattered, was a **corporate form with three properties**.

It was a separate company with its own management. Research was no longer a department inside a manufacturer, competing for attention with production schedules. It had its own president, reporting to a board.

It had a guaranteed income stream not tied to its own output. The Labs were funded by the Bell System — through the arrangements by which Western Electric and the operating companies paid for development work — and the cost was recovered through the rates charged to telephone subscribers under regulatory supervision. The laboratory did not have to sell anything. It did not have to show a return on any particular project. Its budget was a line in the cost base of a regulated utility.

And it was insulated from the ordinary discipline of a capital market. Nobody could buy the company. Nobody could threaten management with a proxy fight over research spending. No competitor could undercut its parent by cutting research and lowering prices.

Set those three properties beside the two preceding studies in this collection and the family resemblance is exact. Colbert's Académie was a group of salaried men, funded from the royal treasury, not required to sell anything, insulated from patronage markets — and it produced results across a century and a half that its funder neither asked for nor could have imagined. **The common element is not genius. It is a funder who cannot be embarrassed by a project that takes ten years and fails.**

The architect's hour here has the framework's three marks. It is **intentional**: identifiable corporate officers executed a reorganisation for stated reasons. It is **skewed toward the position of its designers**, in the open: what was built served AT&T's need for technical supremacy and for a demonstration of public benefit. And it is **bounded**: Jewett and Carty and Arnold made a corporate structure, and everything from Part VI onward happened inside it to people they never met, working on problems they had not conceived.

PART V

What the Money Was Buying

It is worth being exact about why a telephone monopoly spent, at its peak, on the order of two to three per cent of a very large revenue on research, because two different explanations are usually offered and both are partly right.

The engineering explanation. AT&T's business was limited by physics, repeatedly and demonstrably. Distance was limited by attenuation until loading and amplification solved it. Capacity was limited by the number of conversations a wire could carry, until carrier multiplexing and then coaxial cable and then microwave relay and then fibre solved it. Reliability was limited by vacuum tubes and electromechanical switches that wore out. Every one of those constraints was a research problem before it was an engineering problem, and every solution translated directly into revenue or into cost avoided. A firm in that position rationally funds fundamental research, because its production frontier is set by the state of physical knowledge.

That explanation is sufficient for perhaps two-thirds of what the Labs did. It does not explain radio astronomy.

The political explanation. A regulated monopoly is in a permanent negotiation over its own existence. It must satisfy the FCC, state commissions, Congress, the Department of Justice's antitrust division, and a public that has no alternative supplier and knows it. Its whole claim is that a single system serves the public better than competition would.

A laboratory producing Nobel Prizes is, in that negotiation, an asset of a kind nothing else supplies. It is the most legible possible evidence that the monopoly is being used well. It is the answer to the question *what have you done for us*. It converts an argument about market structure — on which reasonable people disagree — into a display of national scientific pre-eminence, on which they do not. And it is politically bipartisan, permanently newsworthy, and immune to the charge of self-interest in a way that no advertising campaign can be.

Both explanations point the same way, which is why the arrangement was stable for sixty years. The engineering case funds the work; the political case protects the funding when a controller asks why a telephone company employs cosmologists. That is a durable equilibrium, and it is the reason the laboratory could sustain long-horizon research through the Depression, a war, and eight administrations.

Two consequences of this funding structure shaped the science, and both are visible in the record.

The first is patience. A researcher at Bell Labs could work on something for a decade without a product. Shannon's information theory took roughly eight years from its wartime origins to publication. The solid-state programme ran from 1945 to a working device at the end of 1947 and to a manufacturable one years after that. No venture-funded firm and few university departments could carry that.

The second is that the problem set was not chosen by fashion. What Bell Labs researchers worked on was, overwhelmingly, some transformation of the company's actual difficulties: transmission, switching, materials, and above all noise. That constraint is usually described as a limitation. It was in fact the source of nearly everything, because the company's difficulties happened to sit on top of some of the deepest questions in twentieth-century physics and mathematics — and the researchers, pursuing an engineering nuisance far enough, kept falling through the floor into fundamental science.

The rest of this study is six instances of falling through the floor.

PART VI

The Men Sent to Find the Noise

The word that runs through this entire institution is *noise*, and it is worth taking literally.

To a telephone engineer, noise is not a metaphor. It is the measurable unwanted energy that arrives at a receiver along with the signal, and it sets the absolute limit on how far a conversation can be carried, how many conversations a cable can hold, and how much a system costs. The Bell System's engineers spent their careers on it. They classified it, measured it, traced it to sources, and eliminated what they could.

And in the course of eliminating it they twice discovered that a component of it was the universe.

The first products of the noise programme were theoretical and are still in every engineering syllabus. In 1928 John B. Johnson at Bell Labs measured the small fluctuating voltage present across any resistor even with no current flowing, and Harry Nyquist supplied the theory: the fluctuation is the thermal agitation of the charge carriers, and its magnitude depends only on temperature, resistance and bandwidth. Thermal noise is now called Johnson–Nyquist noise. It established that there is a floor beneath which no amount of engineering can reduce the noise in a circuit, because the floor is set by the temperature of the matter the circuit is made of.

That is a result of the first importance and it came out of a telephone company measuring hiss.

Nyquist did more. In 1924 and 1928 he published on the maximum rate at which telegraph signals could be sent over a channel of given bandwidth, and Ralph Hartley in 1928 published on the transmission of information — both attacking, in the specific idiom of telephone engineering, the question of how much can be sent through a wire. Those two papers are the direct ancestors of Part VII.

Then there is Karl Jansky, and his story is the purest specimen in this collection of a by-product.

The first transatlantic telephone service opened in 1927. There was no cable capable of carrying voice across the Atlantic; the service ran by shortwave radio, and it was lucrative. It was also plagued by static, which interrupted calls that customers were paying enormously for. Bell Labs wanted to know where the static came from, on the reasonable theory that a source once identified might be avoided or filtered.

They hired a young physics graduate from Wisconsin named Karl Guthe Jansky and gave him that assignment. He built, in a field in Holmdel, New Jersey, a directional antenna about a hundred feet across, mounted on a set of Ford Model T wheels so that it could be rotated to find the bearing of a signal. His colleagues called it the merry-go-round. From August 1931 he recorded.

He found three sources. Some static came from nearby thunderstorms. Some came from distant ones. And there was a third — a steady hiss at about 20.5 megahertz, from no storm, which rose and set.

It rose and set four minutes earlier each day. That is the signature of a source fixed with respect to the stars rather than to the sun, and it means the source is outside the solar system. Jansky worked out the bearing: the centre of the Milky Way, in Sagittarius. He published in 1932 and 1933, and the *New York Times* ran the story, assuring readers that the signals did not appear to come from extraterrestrial beings.

The radio universe was discovered by a telephone company trying to find out what was interfering with its overseas calls.

What happened next is the part that the celebratory accounts omit and that the framework predicts. Investigating star noise, other than as a noise floor to be characterised, did not rank high among AT&T's priorities. Even in 1932 and 1933 Jansky was not working full time on it; his notebooks show substantial effort on the arrival directions of ordinary shortwave transmissions. He asked to build a proper instrument to follow it up. He was refused, and reassigned to other duties. He died in 1950, aged forty-four, with the field he had founded still barely existing.

Radio astronomy was carried forward instead by Grote Reber, an amateur, who built a dish in his back garden in Illinois in 1937 and did the follow-up survey himself.

Position logic reads that refusal as entirely rational and entirely blind, which is what it usually reads. From where AT&T's management stood in 1933, Jansky had completed his assignment: he had identified the sources of static, and the third one was not actionable — you cannot filter the galaxy, and you cannot move it. Further investigation had no conceivable telephone application. They were right about that, and the judgment cost them the founding of a science they had already paid for.

PART VII

The Theory of the Noisy Channel

Claude Shannon joined Bell Labs in 1941. In July and October 1948 the *Bell System Technical Journal* published, in two parts, his paper "A Mathematical Theory of Communication."

It is among the small number of twentieth-century papers that created a field entire, and the thing to notice about it for the purposes of this study is **how completely it is a telephone company's question**.

Set out the position. AT&T sells the transport of messages. Its costs are driven by the capacity and the quality of its physical plant. Every question it faces is some version of: how much can we push down this thing, how badly will it be corrupted, and what would it cost to do better? Nyquist and Hartley had already attacked pieces of that in the 1920s. Shannon's employer had, by 1948, several decades of accumulated engineering intuition about channels, bandwidth, noise and coding, and no general theory tying them together.

What Shannon supplied was the general theory, and it required three moves that nobody had made.

He separated information from meaning. The engineering problem, he observed, has nothing to do with what a message signifies; it concerns reproducing at one point a message selected at another. That abstraction — treating information as a selection among possibilities rather than as content — is what made a mathematics possible.

He gave it a unit and a measure. Information is measured in binary digits — the paper popularised the word *bit*, which Shannon credited to his colleague John Tukey — and the information content of a source is its entropy, a quantity with the same mathematical form as entropy in statistical mechanics.

And he proved the channel capacity theorem. Every channel has a capacity, determined by its bandwidth and its signal-to-noise ratio. Below that rate, messages can be transmitted with arbitrarily small error, by suitable coding. Above it, they cannot.

That last result is the one that changed the world, and it is worth stating what it means, because it is counter-intuitive even now. The engineering assumption before 1948 was that noise degrades a message continuously — that a noisier channel yields a fuzzier signal, and that fidelity is bought by brute force in power and bandwidth. Shannon showed that this is wrong. **Given clever enough coding, a noisy channel can carry information perfectly, up to a hard limit, and no amount of cleverness gets you past that limit.** There is a floor and a ceiling, both computable, and everything in between is an engineering problem with a known answer.

The consequences are not confined to telephony and were not visible from it. Every digital communication system since is an attempt to approach the Shannon limit: modems, mobile telephony, deep-space probes, hard disk drives, optical fibre, Wi-Fi. Data compression is the direct application of the entropy measure. Error-correcting codes are the direct application of the capacity theorem. The claim that this paper is the foundation of the information age is one of the very few statements of that kind in the history of technology that is not an exaggeration.

And nobody commissioned it. Shannon was not assigned to found a discipline. He was a mathematician at a laboratory whose central concern was the corruption of signals, working in an institution that would let him spend years on a problem, on a question that had been in the air in his own building for twenty years because it was his employer's fundamental commercial constraint. The position supplied the question. It did not supply the answer, and it could not have specified in advance what the answer would look like.

That distinction is the framework's whole claim about research, and this is its cleanest instance. **A position determines what questions are in front of people. It does not determine what they find when they look.**

PART VIII

The Amplifier That Did Not Wear Out

The transistor is the exception in this study, and it is important to say so plainly, because a framework that found everything to be an accident would be as untrustworthy as one that found everything to be a plan.

The transistor was aimed at, funded, staffed and hit.

The target was specific and it was a maintenance cost. The Bell System ran on vacuum tubes and electromechanical relays. Tubes are hot, fragile, power-hungry and short-lived; relays are slow and wear out. A national network containing millions of them has an enormous, permanent, irreducible replacement burden. What the company wanted was a solid-state device that could amplify and switch — no filament, no vacuum, no moving parts, nothing to burn out.

Mervin Kelly, who had become director of research in 1936, had wanted this since before the war and had formed a solid-state group then; the war interrupted it. In 1945 he restarted it, larger, under William Shockley and the chemist Stanley Morgan, and it included the experimental physicist Walter Brattain and a newly hired theorist, John Bardeen. Shockley directed the effort toward silicon and germanium — materials whose behaviour had been transformed by wartime work on crystal rectifiers for radar — rather than toward the selenium and copper oxide that had occupied the field before the war.

Shockley's own first idea, a field-effect amplifier, did not work. Bardeen supplied the explanation: electrons trapped in states at the crystal's surface were screening the interior from the applied field. He and Brattain then set out to investigate and defeat those surface states, and in the course of that work built, instead of a field-effect device, a point-contact one — two closely spaced gold contacts on a slab of high-purity germanium, held by a plastic wedge.

On 16 December 1947 it amplified. On 23 December it was demonstrated to the laboratory's senior management, switched in and out of an audio circuit so that the amplification could be heard, with no warm-up time. In January 1948 Shockley conceived the junction transistor, which was the manufacturable form. Bardeen, Brattain and Shockley shared the Nobel Prize in Physics in 1956.

Every element of that is directed research working as advertised: a management that identified a strategic vulnerability, funded a group for a decade including through a war, hired first-rate theorists, allowed the first approach to fail, and got the thing it wanted.

Two qualifications, both of which the framework requires.

The target was narrower than the result by an enormous margin. Kelly wanted a relay and a repeater that would not burn out. What he got was the switching element of every computer that has ever been built, and there is nothing in the 1945 programme documents that anticipates it, because in 1945 the computer was a handful of experimental machines and nobody at AT&T was thinking about them. The transistor's importance is not that it replaced the vacuum tube in telephone exchanges, which it did; it is that it made possible a class of machine that AT&T was not in the business of making and was shortly to be legally barred from making.

And the surface-states work was basic physics done by a theorist following a failure. The device came out of Bardeen's explanation of why Shockley's idea had not worked. That is not the sequence a project plan describes.

What happened to the transistor next is Part IX, and it is the most instructive thing in this study.

PART IX

The Decree That Gave It Away

In January 1949 the Department of Justice sued AT&T under the Sherman Act. The charge was that the Bell System had foreclosed the market for telephone equipment: that by having its operating companies buy from its own manufacturing arm, Western Electric, it had excluded competing suppliers. The remedy sought was divestiture of Western Electric.

The case settled on 24 January 1956, and the settlement is one of the most consequential documents in the history of technology.

AT&T kept everything structurally. There was no divestiture; the FCC had told the Department of Justice it did not consider separating Western Electric necessary. The Bell System remained a vertically integrated monopoly.

In exchange it accepted two constraints.

First, compulsory patent licensing. Bell was required to license all patents issued before the decree **royalty-free** to any applicant, and all subsequently issued patents on reasonable terms. The effect was immediate and enormous: 7,820 patents — about 1.3 per cent of all unexpired United States patents at the time, spread across 266 patent classes — became freely available in 1956. Because of the laboratory's breadth and its wartime work, well over half of that portfolio had its main application outside telecommunications.

Second, a restriction of business. AT&T was prohibited from engaging in any business other than the provision of common carrier communications services. One consequence, which the company's management did not regard as significant at the time, was that AT&T was barred from entering the computer business.

Consider what the first constraint did to the transistor.

AT&T had already been licensing it — it had held a symposium in 1952 and licensed the technology on commercial terms, which is how Texas Instruments and, from 1953, the small Japanese firm then called Tokyo Tsushin Kogyo and later Sony obtained it. But licensing on terms is a very different thing from compulsory royalty-free licensing to any applicant, and the difference falls hardest on exactly the firms least able to negotiate: start-ups, small companies and individual inventors.

The econometric work on this is unusually clean. Watzinger, Fackler, Nagler and Schnitzer, matching Bell patents against comparable non-Bell patents, found that compulsory licensing raised follow-on innovation building on Bell patents by about seventeen per cent in the first five years, and that more than two-thirds of the increase came from young and small companies and unaffiliated individual inventors. They also found the effect was confined to markets **outside** telecommunications — inside telecommunications, where Bell retained other means of exclusion, the decree did nothing, and the exclusionary practices continued until the break-up in 1984.

That second finding is the framework's signature and deserves emphasis. **The remedy worked exactly where the monopolist had no other instrument, and did not work at all where it did.** A legal constraint changes conduct only to the extent that the constrained party lacks an alternative route to the same end. This collection has met that mechanism repeatedly, under the name of the cost-and-credibility condition: an enforced cost changes the *form* of a pursuit, not the pursuit itself. Bell stopped excluding competitors by patent. It went on excluding them by every other means available for another twenty-eight years.

But the diffusion result stands, and it is the one that matters for the question this volume is asking.

The transistor spread through the world's electronics industry at the speed it did because the United States government compelled AT&T to give it away. Not because a laboratory was generous, not because a corporation understood the public interest, and not because of anything in the patent bargain

examined in this collection's preceding study. Because a monopolist bought its structural survival with its intellectual property, and the price was paid to everyone.

PART X

The Operating System They Were Not Allowed to Sell

The second constraint in the 1956 decree — the bar on entering any business but common carrier communications — was the one AT&T's management shrugged at. It produced the larger consequence.

The story begins with a failure. In the mid-1960s Bell Labs joined MIT and General Electric on Multics, an extremely ambitious time-sharing operating system for the GE-645. Bell Labs had joined in order to get a time-sharing system for its own staff. Multics ran vastly over budget and behind schedule — its design documentation reached some three thousand pages — and in early 1969 Bell Labs withdrew.

That left a small group of researchers — Ken Thompson, Dennis Ritchie, Doug McIlroy, Joe Ossanna, Rudd Canaday — with no operating system to work on and a great many opinions about how one ought to be built. Management had cancelled the project and was not minded to buy them a machine.

What Thompson found instead was a Digital Equipment PDP-7 sitting unused in a corner of the building: a four-year-old minicomputer with a base configuration of 4K eighteen-bit words, no software worth mentioning, and constraints severe enough to enforce good design. In August 1969, with his wife and small son away for a month, he wrote the first version — spending, by his own account, about a week each on the operating system, a shell, an editor and an assembler.

The first production deployment inside Bell Labs was for the **patent department**, on a PDP-11/20 in 1971, typesetting patent applications. The way the group got a real machine was by proposing to build a text-processing system, which is what the patent lawyers needed.

In 1972 Dennis Ritchie completed the C language, and in 1973 Unix was rewritten in it — the decision that made the system portable, and that separates Unix from every operating system before it, which had been tied to the machine it was written in assembler for.

And then the 1956 decree determined everything that followed.

AT&T could not sell an operating system. It was barred from the computer business. What it could do was license software for a reasonable fee, and it could not provide support, because supporting a software product would look very much like being in the software business.

So Unix went out to universities under licence, with **source code included**, for a nominal fee, and with no support whatever. Berkeley got it in 1974, when Thompson spent a sabbatical year there. Bill Joy produced the first Berkeley Software Distribution in 1977. The absence of support produced the first user groups, as recipients banded together to help each other, which is the origin of a culture as much as of a technology.

Now assemble what that combination of circumstances actually produced.

Source code included meant students could read the operating system, and did — for a period, Unix was taught by reading it line by line. **A nominal fee** meant every computer science department could afford it. **No support** meant users had to understand it, modify it, and share the modifications. **Written in C and therefore portable** meant it could follow the hardware anywhere. And **owned by a company legally forbidden to commercialise it** meant nobody had to worry that the owner would compete with them.

The lineage from that is the modern computing stack. BSD descends directly from it; macOS and iOS descend from BSD by way of NeXTSTEP. Linux was written in 1991 as a free reimplementation of a Unix-like system, and Android is built on Linux, as is the overwhelming majority of server and cloud infrastructure. The C language is the substrate of essentially all of it.

The most widely used software architecture in human history was given away because a 1956 antitrust settlement made it illegal to sell.

That sentence is the sharpest single statement of this collection's framework that any case has yet supplied. The people who wrote Unix were solving a local problem: they had lost their toy and found a spare machine. The people who set the terms on which it left the building were complying with a decree. The Department of Justice lawyers who wrote the decree in 1956 were trying to stop a telephone monopolist from foreclosing the market in switchboards, and had no conception of software, which barely existed as a category. **Not one participant at any stage was trying to produce the outcome, and the outcome required every one of them.**

The confirming evidence arrived when the constraint was removed. The 1982 consent decree that broke up the Bell System also freed AT&T to enter the computer business — and AT&T promptly began commercialising Unix, raising licence fees, restricting source access, and eventually litigating against the Berkeley distribution. The years of legal uncertainty that followed are widely credited with opening the space that Linux occupied from 1991. **The company behaved exactly as a commercial owner behaves the moment it was permitted to, which is the best possible demonstration that the earlier generosity was not a policy but a legal condition.**

PART XI

The Noise That Was the Universe

In 1960 Bell Labs built a horn-reflector antenna at Holmdel, New Jersey, for Project Echo — an early experiment in bouncing signals off large metallised balloons in orbit. It was a beautiful instrument: a twenty-foot horn, extremely well characterised, designed to receive very weak signals with very low noise, because the entire point of a passive-reflector satellite system is that almost nothing comes back.

Telstar, launched in 1962, carried its own transponders and made the Echo approach obsolete, which freed the antenna.

Two radio astronomers at the Labs had been waiting for it. Arno Penzias, who had joined in 1958 with a Columbia doctorate on using masers to measure faint radio signals, and Robert Wilson, who arrived in 1962 from Caltech, both wanted to use the horn as a radio telescope.

When they did, in 1964, they found an excess. There was a uniform microwave signal, coming from every direction equally, corresponding to an antenna temperature of a few degrees above absolute zero, which they could not account for and could not eliminate.

What they then did is the reason they are in this study rather than in a footnote. They spent the better part of a year assuming it was their own equipment's fault and trying to find the fault. They checked the receiver. They checked for interference from New York City. They dismantled and rebuilt joints in the horn. They discovered that a pair of pigeons had nested in the throat of the antenna and coated it in what Penzias later described in the sanitised term the company preferred; they evicted the pigeons, cleaned the horn, and the signal did not change.

It was isotropic, it did not vary with the time of day or the season, and it would not go away.

Meanwhile, thirty miles away at Princeton, Robert Dicke and James Peebles had been working out that if the universe began in a hot dense state, it should be filled with the cooled remnant of that radiation, and that the remnant should now be observable as microwaves. They were building an antenna to look for it.

Late in 1964 Penzias learned of the Princeton work. He telephoned Dicke. The two groups met, and published in the summer of 1965 as a pair of papers in the *Astrophysical Journal* — Penzias and Wilson reporting the excess antenna temperature at 4080 megahertz in a paper whose title claims nothing at all, and Dicke, Peebles, Roll and Wilkinson supplying the interpretation.

The cosmic microwave background is the strongest single piece of evidence for the hot big bang, and its discovery is the moment cosmology became an observational science. Penzias and Wilson shared the Nobel Prize in Physics in 1978.

Now note the shape of it, because it is the shape of the whole institution.

Two men were assigned to a satellite communications antenna. Their professional formation was in the measurement and elimination of noise, because that is what a communications laboratory trains people to do and what that instrument was built for. They found noise they could not eliminate. Because they were rigorous engineers in a culture that treated unexplained noise as a defect to be hunted down, they refused to accept it, and pursued it for a year past the point at which anyone with a deadline would have stopped.

And the noise was the universe.

Thirty-two years and about a mile separate Karl Jansky's merry-go-round from the Holmdel horn. Both men were employed to find out what was interfering with a communications channel. Both found something that was not interference. The first was told to stop; the second was allowed to continue, because by 1964 the laboratory had a culture and a budget that the laboratory of 1933 did not.

That difference is the strongest thing that can be said for the arrangement described in Part V. What the monopoly bought, in the end, was the freedom to keep looking after the engineering question had been answered.

PART XII

The Breakup

In November 1974 the Department of Justice sued AT&T again. This time the objective was structural and this time it was achieved.

The intervening decades had eroded the 1956 settlement from several directions. The FCC's *Carterfone* decision in 1968 had ended AT&T's ability to bar customers from attaching equipment it had not made. Microwave technology had made competitive long-distance carriage physically possible, and MCI had begun providing it and suing over interconnection. The natural-monopoly argument that had justified the whole structure since Vail was, by the 1970s, technologically obsolete in exactly the segment that carried the profits.

The case settled in January 1982. On 1 January 1984 the Bell System was divested: AT&T retained long-distance, Western Electric and Bell Labs, and gave up the twenty-two local operating companies, which were reorganised into seven regional holding companies. In exchange, AT&T was released from the 1956 restriction and permitted to enter the computer business.

What happened to the laboratory is the coda this study needs.

Its funding mechanism disappeared. Bell Labs had been financed out of the revenues of the entire Bell System under regulatory cost recovery. After 1984 it was the research arm of a long-distance carrier facing competition, and its costs had to be justified against the returns of that business. A separate organisation, Bellcore, was created to serve the regional companies' shared research needs, taking a substantial share of the staff.

Its time horizon shortened, for the reasons the framework predicts. A firm in a competitive market cannot fund a physicist for a decade on a problem with no product, because a competitor who does not will undercut it. This is not a failure of management vision; it is the ordinary discipline of markets working as designed, applied to an institution that had been built specifically to be exempt from it.

And it was progressively dismembered. In 1996 AT&T spun off its equipment business as Lucent Technologies, taking most of Bell Labs with it. Lucent was hit hard by the telecoms collapse of the early 2000s, merged with Alcatel in 2006, and was acquired by Nokia in 2016. The laboratory still exists and still does good work. It is not what it was, and nobody claims otherwise.

The lament that has grown up around this — that a unique instrument of national research capacity was destroyed by antitrust dogma — is worth taking seriously and worth qualifying in two directions.

In its favour: the structure genuinely was unusual, genuinely did fund things no other structure would, and its dissolution genuinely did remove a source of long-horizon industrial research that has not been replaced by anything with the same characteristics.

Against it: the arrangement was paid for by monopoly rents extracted from every telephone subscriber in the United States, and long-distance rates fell substantially after divestiture. The same break-up that ended the laboratory's funding also produced the competitive market in equipment and services that made the following two decades of telecommunications possible. And the two consequences of Bell Labs that this study has identified as world-changing — the diffusion of the transistor and the release of Unix — were both produced by antitrust action against AT&T's interest, not by the arrangement the lament is mourning.

Antitrust broke the laboratory. It had also, twice, been the reason the laboratory's products got out.

PART XIII

The Ledger

Both columns, in ink.

In the column of the achievements, which are among the largest any single institution has ever produced: the transistor, and with it the entire semiconductor industry; information theory, which is the mathematical foundation of all digital communication and storage; Unix and the C language, which are the substrate of modern computing; the discovery of cosmic radio emission and of the cosmic microwave background, which founded radio astronomy and made cosmology observational; the first practical silicon solar cell in 1954; the charge-coupled device; the theoretical basis of the laser; the cellular concept; thermal noise theory; and a long list of transmission and switching technologies that made a continental and then a global telephone network work. Researchers at the laboratory have shared in a series of Nobel Prizes — the count is given variously between seven and ten depending on how affiliation is reckoned — and Thompson and Ritchie took the Turing Award in 1983. Whatever the correct number, the laboratory's output is without close parallel in the history of industrial research.

In the column of the costs: all of it was paid for by a monopoly. The rates that funded the laboratory were charged to every household and business in the United States that wanted a telephone, and they were higher than a competitive market would have produced — long-distance prices fell sharply after divestiture, which is the clearest available measure of what had been extracted. That is a levy on communication, collected from everyone, spent at the discretion of a corporation, and it is regressive in the way all flat levies are.

The company defended that position hard and not always honourably. It used tariffs to prevent customers attaching equipment it had not manufactured, a practice that took the *Hush-A-Phone* and *Carterfone* decisions to break. The 1956 decree's compulsory licensing produced no measurable increase in innovation inside telecommunications, because Bell retained other means of exclusion and used them until 1984. And there is a serious scholarly argument — associated particularly with Mark Clark's work, and flagged here as contested rather than settled — that the Bell System delayed the commercial development of magnetic recording out of concern that recorded telephone calls would inhibit telephone use. Mobile telephony makes the same point in a form that is not disputed: the cellular concept was described inside Bell Labs in 1947, and commercial cellular service did not begin in the United States until 1983, a delay in which FCC spectrum policy and AT&T's own priorities both had substantial parts.

The case resolves, as this project's cases tend to, against both easy pictures.

It was not a philanthropic enterprise. No one at AT&T set out to advance human knowledge. The laboratory was a corporate reorganisation of 1925, built on a regulatory settlement of 1913 and 1921, funded because a firm whose production frontier was set by physics needed physicists, and protected because a monopoly holding its position on a public-benefit argument needs continuous, legible, unimpeachable evidence for that argument. Every dollar was justified on one of those two grounds.

And it was not an accident. Kelly's solid-state programme was a decade-long directed effort at a stated target and it hit. The founding was executed by named officers for stated reasons. The 1956 and 1982 decrees were deliberate acts of government. The men who did the work were hired, paid, equipped and in most cases pointed.

It was an architect's hour, and then another — 1907, 1913, 1921, 1925, 1934, 1945, 1956, 1969, 1982 — each a bounded episode in which real people solved a pressing problem with the materials at hand, skewed the settlement toward their own position, and then handed the result to a structure that carried it forward on a logic none of them chose.

Now the two findings this volume was written for.

The first is about what a position determines. It does not determine what people find. It determines what they are looking at when they find it. AT&T's engineering obsession was noise — the unwanted energy that limits every communication channel — and the institution therefore assembled, over sixty years, the largest concentration of people in the world whose training, instruments and professional instinct were directed at detecting and characterising very faint unwanted signals. Point that capability at the sky twice, three decades apart, and it finds the galactic centre and then the residual heat of the origin of the universe. Ask it to state the general limit on how much can be pushed through a corrupted channel and it produces the mathematics of information. Ask it for an amplifier that will not burn out and it produces the switching element of every computer ever built.

None of those results was in anyone's plan. All of them are legible consequences of a single narrow commercial preoccupation, pursued with unusual resources by unusually good people for an unusually long time. **The company's obsession was the seed and the answers were nobody's.**

The second is about who gets the credit, and it is the harder one.

This collection's standing rule, in the symmetric form established two volumes ago, is that legibility is not pardon and it is not credit either. Bell Labs is the case that puts real pressure on it, because here the goods are enormous and the institution is genuinely admirable and the temptation to hand it the laurel is strong.

The record does not support the simple version. AT&T built and funded a magnificent instrument, for reasons of its own, and deserves what follows from that. But the two outputs that most changed the world did not reach the world through AT&T's choice. **The transistor diffused because the Department of Justice compelled royalty-free licensing of 7,820 patents in 1956. Unix diffused because the same decree made it illegal for AT&T to sell software, so the company gave it away with source code and no support — and the moment the decree was lifted in 1982, AT&T began charging for it and suing over it.** The generosity was a legal condition, and it ended the instant the condition did.

So the honest distribution is this. The laboratory produced the things. The monopoly paid for them, with money taken from everyone. And the escape — the part that made them matter to eight billion people rather than to a telephone company — was compelled by lawyers who were trying to fix the market in switchboards and had never heard of an operating system.

The most consequential thing in this story is not a genius and not a laboratory and not a plan. It is a hiss on a wire that a company could not tolerate, and a settlement clause that a company's managers thought too trivial to argue about.

Held, like everything in this project, as tested, not revealed.

A Note on Sources

This is a work of synthesis, and every quotation and figure has been verified to a published source; none is invented. Where scholarship is divided, the division is reported.

On the institution generally. The standard narrative history is Jon Gertner, *The Idea Factory: Bell Labs and the Great Age of American Innovation* (Penguin, 2012); the standard technical history is the multi-volume *A History of Engineering and Science in the Bell System* published by the Laboratories themselves, which is authoritative on chronology and is a corporate account. Narda Jones and the AT&T Archives material, the Computer History Museum's *Silicon Engine* series, the IEEE's *Engineering and Technology History Wiki*, and the American Physical Society's historic-sites documentation are used as indicated. Readers should note that a large share of the accessible material on this subject originates with AT&T or its successors.

On transmission and the landscape. The physics of attenuation and distortion on open wire; the independent work of Michael Pupin and George Campbell on loading coils in the 1890s and AT&T's deployment of them from 1900; the acquisition of rights to Lee de Forest's audion in 1913 and Harold Arnold's development of the high-vacuum tube; and the first transcontinental telephone call from New York to San Francisco on 25 January 1915 — follow the standard histories of the Bell System.

On the regulatory settlement. Theodore Vail's return to the AT&T presidency in 1907 and his statement in that year's annual report that regulation, provided it were independent, intelligent, considerate, thorough and just, was an acceptable substitute for competition, follow the AT&T corporate history and the standard accounts. The Kingsbury Commitment of December 1913 — Nathan Kingsbury's letter to the Attorney General agreeing to divest the controlling interest in Western Union acquired in 1909, to allow non-competing independent telephone companies to interconnect with the AT&T long-distance network, and to refrain from acquisitions to which the Interstate Commerce Commission objected — follows the standard sources; so does the observation that AT&T did not agree to interconnect its local services with other local providers, nor to interconnect with independent long-distance carriers, and was permitted to buy subscribers provided it sold an equivalent number. The Willis-Graham Act of 1921 and the Communications Act of 1934 establishing the FCC follow the same literature.

On the founding of the Laboratories. The incorporation of Bell Telephone Laboratories on 1 January 1925 consolidating the development and research activities of the Bell System; the initial complement of about 3,600 engineers, scientists and support staff in some 400,000 square feet; the even division of ownership between Western Electric and AT&T; John J. Carty as first chairman and Frank B. Jewett as first president to 1940; and the earlier combination of the AT&T and Western Electric engineering departments in 1907 — follow the standard sources and the contemporary trade press of 1925. Harold Arnold's description of the intended field of his research department, extending from physical and organic chemistry through metallurgy, magnetism, electrical conduction, radiation, electronics, acoustics, phonetics, optics, mathematics and mechanics to physiology, psychology and meteorology, is quoted in Watzinger et al. (below).

On noise and Jansky. Johnson's 1928 measurement of thermal noise and Nyquist's theoretical account of it; Nyquist's 1924 and 1928 papers on telegraph transmission rates; and Hartley's 1928 paper on the transmission of information — follow the standard engineering literature. Karl Jansky's employment to investigate static affecting the transatlantic radiotelephone service opened in 1927; the rotating antenna at Holmdel; the recording from August 1931; the identification of local storms, distant storms and a third residual hiss at about 20.5 MHz; the four-minute daily drift indicating a sidereal rather than a solar source; the identification of the direction as the centre of the Milky Way in Sagittarius; and publication in 1932 and 1933 with coverage in the *New York Times* — follow the standard accounts and Britannica. That Jansky did not work full time on star noise even in 1932–33, that his notebooks show substantial effort on the arrival directions of shortwave transmissions, that further investigation did not rank high among AT&T's priorities, and that he was subsequently reassigned, follow George Southworth's 1956 retrospective and the account in Springer's history of radio astronomy at Bell Labs. Grote Reber's independent follow-up from 1937 is standard.

On Shannon. "A Mathematical Theory of Communication," *Bell System Technical Journal* 27, July and October 1948. The separation of engineering from semantic questions, the entropy measure, the credit to John Tukey for the word *bit*, and the noisy-channel coding theorem establishing that arbitrarily reliable transmission is possible below a computable capacity and impossible above it, follow the paper and the standard secondary literature.

On the transistor. Mervin Kelly's formation of a solid-state research group as director of research in 1936 and his reconstitution of it, larger, in 1945 under William Shockley and Stanley Morgan, including Walter Brattain and John Bardeen with Robert Gibney, Bert Moore and John Pearson; the focus on germanium and silicon rather than selenium and copper oxide in consequence of wartime radar crystal-detector work; the failure of Shockley's field-effect approach; Bardeen's account of surface states; the point-contact device using two closely spaced gold contacts on high-purity germanium held by a plastic wedge; amplification achieved on 16 December 1947 and demonstration to Bell Labs management on 23 December; Shockley's conception of the junction transistor in January 1948; and the 1956 Nobel Prize in Physics shared by Bardeen, Brattain and Shockley — follow the Computer History Museum's *Silicon Engine*, IEEE Spectrum, the IEEE Electron Devices Society, the American Physical Society historic-site documentation, and the Engineering and Technology History Wiki. The 1952 transistor symposium and the licensing of the technology, including to Texas Instruments and to Tokyo Tsushin Kogyo (later Sony) from 1953, follow the same literature and the case study in Watzinger et al.

On the 1956 consent decree. The 1949 Sherman Act suit alleging foreclosure of the telecommunications equipment market and seeking divestiture of Western Electric; the FCC's advice that divestiture was unnecessary; the consent decree of 24 January 1956; the requirement to license all patents issued before the decree royalty-free to any applicant (excepting RCA, General Electric and Westinghouse, which held prior cross-licences) and subsequent patents on reasonable royalties; the consequent free availability of 7,820 patents in 266 patent classes, about 1.3 per cent of all unexpired US patents, of which some 58 per cent had their principal application outside telecommunications; and the restriction of the Bell System to common carrier communications services, with the incidental effect of barring AT&T from the computer business — follow Martin Watzinger, Thomas A. Fackler, Markus Nagler and Monika Schnitzer, "How Antitrust Enforcement Can Spur Innovation: Bell Labs and the 1956 Consent Decree," *American Economic Journal: Economic Policy* 12:4 (2020), and the Federal Judicial Center's account of *United States v. AT&T*. The

finding that compulsory licensing raised follow-on innovation by about 17 per cent in the first five years, that more than two-thirds of the increase came from young and small firms and unaffiliated inventors, and that the effect was confined to markets outside telecommunications where Bell retained other means of exclusion, is theirs.

On Unix. Bell Labs' participation in and withdrawal from Multics in 1969; Thompson's use of a disused PDP-7 with a base configuration of 4K eighteen-bit words; the writing of the first version in August 1969; the naming pun credited to Brian Kernighan; the first production deployment for the Bell Labs patent department on a PDP-11/20 in 1971 for typesetting patent applications; Ritchie's completion of C in 1972 and the rewriting of Unix in it in 1973; the licensing of source code to universities for a nominal fee with no support in consequence of the 1956 decree's bar on the computer business; Thompson's Berkeley sabbatical and Bill Joy's first Berkeley Software Distribution; and the 1983 Turing Award to Thompson and Ritchie — follow the standard histories, including Peter Salus's account as reported in the fortieth-anniversary coverage, and the Unix chronologies maintained in the community. The post-1982 commercialisation of Unix by AT&T and the subsequent litigation over the Berkeley distribution follow the standard accounts and are noted here as the confirming case.

On Penzias and Wilson. The Holmdel horn-reflector antenna built in 1960 for Project Echo and freed for research after Telstar's launch in 1962; Penzias's arrival in 1958 and Wilson's in 1962, both with doctoral work on maser amplification of weak radio signals; the detection in 1964 of an isotropic excess corresponding to a few degrees of antenna temperature; the year spent eliminating instrumental explanations including the removal of nesting pigeons; the independent prediction by Robert Dicke and James Peebles at Princeton; and the pair of 1965 papers in the *Astrophysical Journal*, with Penzias and Wilson reporting the excess antenna temperature at 4080 MHz and Dicke, Peebles, Roll and Wilkinson supplying the cosmological interpretation; and the 1978 Nobel Prize in Physics — follow the Nobel lectures of Penzias and Wilson, the standard cosmological histories, and the Carnegie and PBS accounts.

On the break-up and its aftermath. The 1968 *Carterfone* decision; MCI's entry and litigation; the Department of Justice suit of November 1974; the consent decree of January 1982; the divestiture effective 1 January 1984 separating the twenty-two local operating companies into seven regional holding companies while AT&T retained long-distance, Western Electric and Bell Labs and was released from the 1956 line-of-business restriction; the creation of Bellcore; the Lucent spin-off of 1996; the Alcatel merger of 2006; and the Nokia acquisition of 2016 — follow the Federal Judicial Center's account, the standard telecommunications histories, and the corporate record.

On the costs. The *Hush-A-Phone* and *Carterfone* proceedings concerning foreign attachments follow the FCC record. **The argument that the Bell System deliberately retarded the commercial development of magnetic recording is associated particularly with Mark Clark's work and is flagged here as contested rather than settled.** The description of the cellular concept within Bell Labs in 1947 and the commencement of commercial US cellular service in 1983 are not in dispute; the apportionment of responsibility for the interval between FCC spectrum policy and AT&T's own priorities is, and is reported as such. The variation in the count of Nobel Prizes associated with the Laboratories, given in different sources as between seven and ten depending on how affiliation is reckoned, is reported rather than resolved.

On the framework. The concepts of *position*, the *field of the visible*, *convergence*, the *architect's hour*, the *institution's logic* and the *cost-and-credibility condition* belong to the Patterns of Power project of which this paper is part and are developed across its studies, in particular *Position Logic* and *Against the Historian's Re-*

flex. The symmetric statement of the collection's standing rule — that legibility is not credit any more than it is pardon — is developed in *The Measure of the Earth*, whose account of a patient state funder is the direct comparison drawn in Part IV. The treatment of patents as an instrument of exclusion and of disclosure follows *The Bargain Nobody Struck*. Where this study's claims err, they should err visibly, in a form the cited scholarship can correct.

Part of the collection Patterns of Power. Tested, not revealed.